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Shallow conditioning and late fertilizer application effects on the quality of conifer nursery stock in British Columbia

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ABSTRACT

Shallow undercutting and wrenching (conditioning) of British Columbia conifers was compared with the standard nursery regime. The application of a complete NPK fertilizer some 50 days prior to lifting was also tested. Shallow conditioning combined with late fertilizer application can improve the root growth capacity at lifting of the conifers grown in British Columbia. It cannot replace cold exposure as a method of hardening Douglas-fir, and although it had no adverse effect on the other species tested, it had minimal effect on survival after field planting and reduced initial height increment.

The application of fertilizer just prior to lifting can improve the early growth of the trees without adversely affecting survival, and warrants additional work to quantify type and rate of fertilizer for each species. Planting seedlings some 5 cm deeper than they stood in the nursery proved an effective way of improving their establishment.

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INTRODUCTION

Shallow undercutting followed by frequent wrenching at the same depth was first developed in its modern form in New Zealand (Van Dorsser and Rook 1972). This process, known as conditioning, is widely practised in New Zealand and Australia (Bacon and Hawkins 1977; Benson and Shepherd 1977) and has allowed the use of bareroot seedling planting stock in South African planting programs (Donald 1976; Denison 1982). The species used in these countries, unlike those used in British Columbia, seldom develop a natural dormancy in the seedling stage. Conditioning, by inducing shoot dormancy and stimulating the production of a compact fibrous root system, allows the seedlings to be planted successfully even during the growing season.

Undercutting and wrenching are used to prepare 2-year-old stock for planting in western North America, but the depth of these operations 18-20 cm (Tanaka et al. 1976; van den Driessche 1983) and 25 cm (Duryea and Lavender 1982) is greater than those used in the warm temperate regions of the southern hemisphere.

Eight trials on 2+0 stock of six species in four nurseries were conducted to compare the effect of shallow conditioning (undercutting and wrenching at 10 cm) with that of the currently accepted or standard conditioning regime (undercutting and wrenching at 20 cm). This paper describes the results from these trials. It is divided into two sections covering (1) nursery results and storage, and (2) field performance of the stock.

NURSERY SECTION

Methods and Materials

Each trial consisted of a 2 x 3 factorial with six replications in a randomized block design. The treatments were two degrees of conditioning, shallow and standard, and three levels of fertilizer applied approximately 50 days prior to lifting: 0, 1.25, and 2.50 g of 4-12-8 fertilizer per seedling. Beds were 1.1 m wide and, plots 2.5 m. A complete fertilizer was used in these trials because (1) there was not time to test different levels of the different elements, and (2) it appeared logical that a fertilizer suitable for growth of conifers (Donald 1972) would be equally suitable for late application, particularly as the soil into which the newly developed root system would be growing would already have been largely depleted during normal nursery growth. Table 1 lists the nurseries, species, and seedlots used. Shallow conditioning involved the undercutting of the roots at 10 cm with minimal disturbance, followed by weekly wrenching at the same depth. The wrenching operation lifted or jolted the seedlings and broke the soil layer in which the roots occurred. Undercutting commenced the last week of July and the first week of August 1979, and wrenching continued for a minimum of 14 weeks. This work was done manually with a flat spade at all nurseries except Red Rock, where a Marsh reciprocating wrencher was used. The Marsh was used for standard conditioning in all nurseries.

Plants were lifted between the last week of October and the first week of November 1979. After lifting for planting and/or storage, a random sample of 41 seedlings was taken for each plot, the roots lightly washed, and 16 prepared for root growth capacity (RGC) measurement (Burdett 1979). The delay between lifting and RGC measurement did not exceed 5 days. The seedlings, from which all new white roots were removed, were potted in a 3:1, peat:vermiculite mix to which lime had been added. Once potted, the seedlings were watered and placed a in growth chamber. The chamber was maintained at 30°C for 16 hours with 400 μmol $m^{-2}s^{-1}$ PPFD, and at 25°C for 8 hours in the dark. Relative humidity was maintained at 75%. The seedlings were kept in this regime for 7 days, and watered every second day.

TABLE 1. Nurseries and species used in the conditioning/fertilizer trials, shown by seedlot number

Nursery Layout date	Red Rock 1979-7-17	Skimikin 1979-7-12	Surrey 1979-8-7	Campbell River 1979-8-14
Interior spruce (*Picea engelmannii* Parry)		1365		
Interior spruce (*Picea glauca* (Moench) Voss)	2210		1868	1409
Sitka spruce (*Picea sitchensis* (Bong.) Carr.)				2793
Lodgepole pine (*Pinus contorta* Dougl.)	1804			
Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco)		149*		391**

* Interior variety *glauca* (Blissn.) Franco

** Coastal variety *menziesii* (Mirb.) Franco

On removal from the chamber, the plants were taken from the growing media, again lightly washed, and the number of new white roots counted. The scoring system developed by Burdett (1979) was used in a slightly modified form. The number of roots less than 1 cm were scored as 0 for none, 0.5 for 1 to 10, 1.0 for more than 10. These values were added to the Burdett scale. Although the Burdett scoring system allows rapid assessment, the actual total number of new roots produced could be a more sensitive measure of treatment response. To test this, all new roots of 2 mm or more were counted for each seedling from two blocks of each of the four interior spruce trials.

Shoot length, root collar diameter, and oven-dry weight were measured on the remaining 25 seedlings for all trials. The dry seedlings were separated into foliage, stems, and roots, then ground and analysed for nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) content. Nitrogen was determined by Micro-Kjeldahl, P by the vanadophosphoric method, and the cations, K, Ca, and Mg, by atomic absorption.

Coastal species were lifted in autumn and stored with moist foliage at 2°C for planting early the following year. Interior species were stored at -2°C with dry foliage for planting the following spring. When the seedlings were removed from storage for planting, RGC was measured on a further 16 seedlings from each plot. Data obtained from the RGC tests and morphological measurements were subjected to analyses of variance. Tissue analyses data were subjected to multivariate and univariate analyses.

Results

Root growth capacity

Coastal Douglas-fir and Sitka spruce

With both these coastal species, RGC showed a significant interaction (5% level) between the conditioning treatment and fertilizer application. Pre-storage RGC was only increased by shallow conditioning when the treatment was combined with late fertilizer application (Figs. 1 and 2). The 1.25-g level of fertilizer appeared to be adequate, not differing significantly from the 2.50-g level. Fertilizer application had no effect on the RGC of seedlings given the standard conditioning treatment.

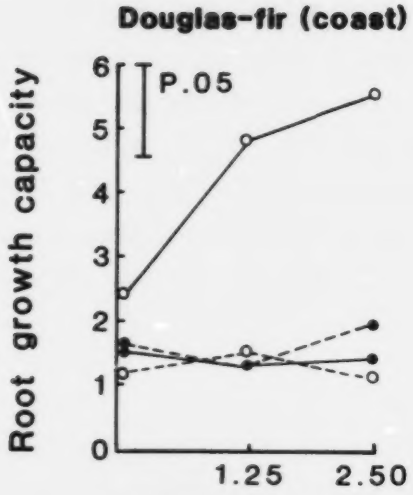
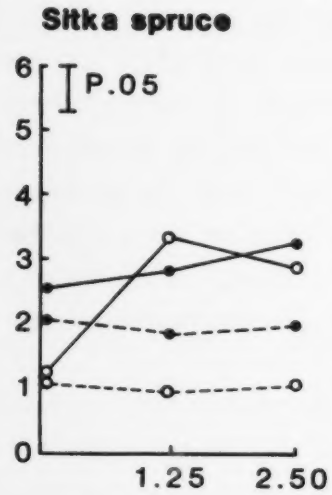


FIGURE 1.



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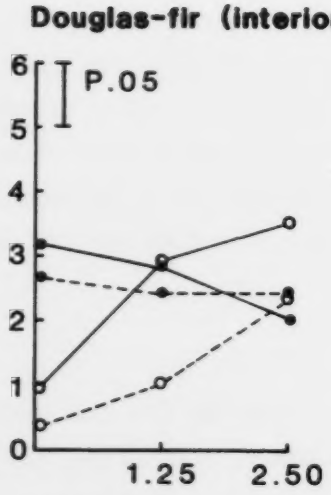

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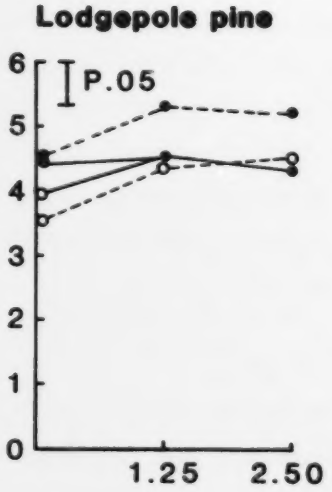


FIGURE 4.

FIGURES 1.- 4. The effect of late applications of 4-12-8 fertilizer on pre-storage (open circles) and post-storage (solid circles) root growth capacity (modified Burdett scale) or standard-(broken lines) and shallow-conditioned (solid lines) planting stock. Each point is a mean value of 96 seedlings, taken as samples of 16 from each of the six treatment blocks.

Storage for 6 months reduced the RGC of shallow-conditioned Douglas-fir stock, particularly if it had been fertilized. After storage, RGC of shallow conditioned and standard conditioned Douglas-fir stock did not differ significantly whether it was fertilized or not (Fig. 1). The RGC of standard-conditioned Sitka spruce, whether fertilized or not, and shallow-conditioned stock that had not received fertilizer, were increased by 3 months' storage. Shallow-conditioned Sitka spruce stock that had received fertilizer was unaffected by storage (Fig. 2).

Interior Douglas-fir and lodgepole pine

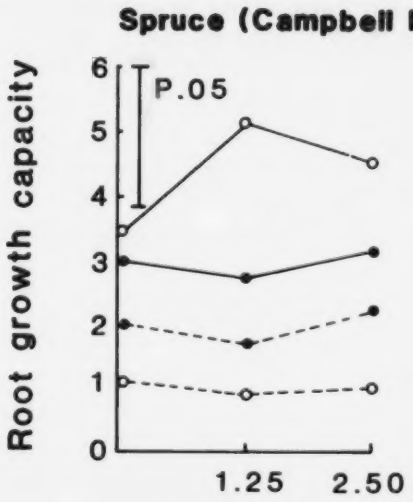
Shallow conditioning improved the pre-storage RGC of interior Douglas-fir at Skimikin, but had no significant effect on the lodgepole pine at Red Rock. Fertilizer application improved the pre-storage RGC of both species. The highest level (2.50 g) was required to ensure a significant difference from the zero level at Skimikin, whereas the 1.25-g level was sufficient at Red Rock (Figs. 3 and 4). No interactions were significant.

Storage for 6 months improved the RGC of standard-conditioned stock of interior Douglas-fir, but the fertilized stock that had an improved RGC at lifting failed to maintain this improvement through storage (Fig. 3). Lodgepole pine that received the standard conditioning improved RGC following 7 months' storage. Shallow-conditioned lodgepole pine neither improved nor deteriorated (Fig. 4).

Interior spruce

Shallow conditioning significantly improved the pre-storage RGC of interior spruce at the Campbell River, Skimikin, and Surrey nurseries. It had no effect at Red Rock (Figs. 5-8). Late fertilizer application had little effect on pre-storage RGC of interior spruce. At Red Rock, however, standard-conditioned stock did respond quadratically (Table 2).

When the total number of new roots produced was used instead of the modified Burdett scale to assess the effect of treatment, the response to conditioning was unchanged, but the effect of the fertilizer treatment was



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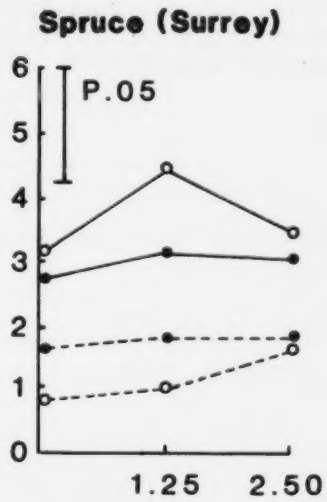

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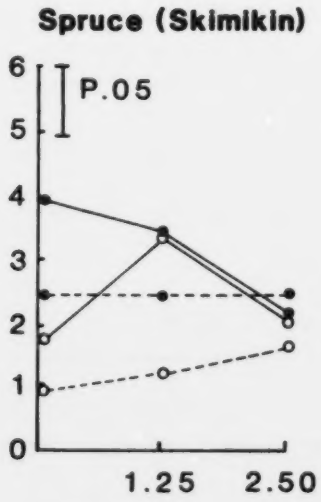

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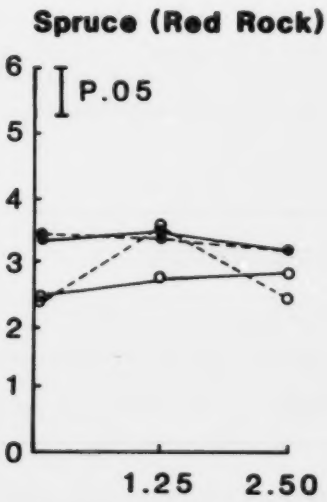

FIGURE 8.

FIGURES 5.- 8. The effect of late applications of 4-12-8 fertilizer on pre-storage (open circles) and post-storage (solid circles) root growth capacity (modified Burdett scale) or standard-(broken lines) and shallow-conditioned (solid lines) planting stock. Each point is a mean value of 96 seedlings, taken as samples of 16 from each of the six treatment blocks.

TABLE 2. The effect of conditioning and late fertilizer treatments on the pre-storage RGC of interior spruce, Red Rock Nursery (modified Burdett scale)

Conditioning	g 4-12-8/seedling			Interaction table	
	0	1.25	2.50	SE	LSD ($p \leq .05$)
Standard	2.3	3.5	2.4	0.4	0.8
Shallow	2.4	2.7	2.8		

TABLE 3. The effect of late fertilizer application on the pre-storage RGC of interior spruce, averaged for Campbell River, Skimikin, and Surrey nurseries (all new roots $\geq$ 2mm)

g 4-12-8/seedling				
0	1.25	2.50	SE	LSD ($p \leq .01$)
33.8	78.3	87.0	9.3	38.0

clearly evident (Table 3). There were no interactions between conditioning and fertilizer treatments for interior spruce at Campbell River, Skimikin, or Surrey whether the assessment was made with the modified Burdett scale or the total root count.

Storage for 7-8 months improved the RGC of standard-conditioned interior spruce at all four nurseries, though the response was not always significant. The RGC of shallow-conditioned stock, particularly if it received a late fertilizer application, was adversely affected by storage, although it was still better than or as good as the improved RGC of stored standard-conditioned stock, (Figs. 5-8).

Seedling morphology

Shoot length and root collar diameter were not significantly affected by either the conditioning or the fertilizer treatments at any nursery. Total dry weight of Sitka spruce and interior spruce (Red Rock) were reduced by shallow conditioning. The responses were significant at the 1% level: they were 2.05-1.51 g and 1.02-0.88 g, respectively. There were no other significant differences in dry weight.

Tissue analyses

Multivariate analyses of variance of each trial was used to determine the effect of the treatments on the nutrient levels of all three portions of the plant simultaneously. Univariate analyses were then used to interpret the significant responses (Tables 4-10).

In most cases where significant treatment differences occurred, shallow conditioning reduced the percent nutrient content and the seedling tissues below that of the standard-conditioned stock. Exceptions to this were most prevalent in the roots (six times), but also occurred in the stems (twice) and in the foliage (once). Root tissue increases occurred in N and P with Sitka spruce, in K with interior spruce (Campbell River), in Mg with interior spruce (Surrey) and lodgepole pine, and in Ca with

TABLE 4. Nutrient content (% dry weight) of coastal Douglas-fir tissues as affected by conditioning and fertilizer treatments

Conditioning		Standard			Shallow			Treatment significance			
Fertilizer rate (g 4-12-8/plant)		0	1.25	2.50	0	1.25	2.50	Cond	Fert	CxF	Error Ms
Needles	N	1.50	1.55	1.46	1.46	1.72	1.73	*	-	*	0.0220
	P	0.12	0.12	0.12	0.12	0.11	0.11	-	-	-	0.0001
	K	0.73	0.73	0.70	0.72	0.76	0.72	-	-	-	0.0041
	Ca	0.39	0.37	0.39	0.32	0.33	0.34	**	-	-	0.0008
	Mg	0.11	0.10	0.11	0.08	0.09	0.10	**	-	-	0.0001
Stems	N	0.75	0.77	0.73	0.66	0.91	0.98	-	*	*	0.0243
	P	0.10	0.10	0.10	0.10	0.10	0.10	-	-	-	0.0001
	K	0.50	0.52	0.48	0.52	0.48	0.50	-	-	-	0.0025
	Ca	0.26	0.25	0.27	0.20	0.21	0.22	**	-	-	0.0004
	Mg	0.07	0.07	0.08	0.07	0.06	0.07	**	-	-	0.0001
Roots	N	0.76	0.72	0.70	0.74	1.07	1.02	**	*	**	0.0150
	P	0.12	0.13	0.12	0.12	0.14	0.14	**	*	**	0.0001
	K	0.42	0.43	0.38	0.44	0.39	0.32	-	**	*	0.0019
	Ca	0.27	0.27	0.31	0.20	0.24	0.24	**	**	-	0.0015
	Mg	0.08	0.09	0.09	0.08	0.09	0.10	-	-	-	0.0002

- = not significant * = 5% significance level ** = 1% significance level

TABLE 5. Nutrient content (% dry weight) of Sitka spruce tissues as affected by conditioning and fertilizer treatments

Conditioning		Standard			Shallow			Treatment significance			
Fertilizer rate (g 4-12-8/plant)		0	1.25	2.50	0	1.25	2.50	Cond	Fert	CxF	Error Ms
Needles	N	1.63	0.64	1.67	1.60	1.82	2.14	*	*	*	0.0655
	P	0.17	0.17	0.17	0.19	0.19	0.20	**	-	-	0.0004
	K	0.76	0.89	0.86	0.91	0.84	0.86	-	-	-	0.0196
	Ca	0.63	0.60	0.62	0.60	0.57	0.59	-	-	-	0.0036
	Mg	0.14	0.15	0.14	0.14	0.13	0.14	-	-	-	0.0003
Stems	N	0.84	0.86	0.86	0.96	1.09	1.09	**	-	-	0.0201
	P	0.15	0.13	0.13	0.16	0.15	0.14	-	-	-	0.0005
	K	0.52	0.55	0.57	0.62	0.56	0.55	-	-	*	0.0047
	Ca	0.33	0.30	0.31	0.34	0.31	0.30	-	**	-	0.0007
	Mg	0.10	0.09	0.10	0.11	0.10	0.09	-	-	-	0.0001
Roots	N	0.88	0.84	0.93	1.03	1.34	1.43	**	**	**	0.0118
	P	0.14	0.15	0.15	0.16	0.18	0.18	**	-	-	0.0002
	K	0.51	0.50	0.50	0.52	0.55	0.51	-	-	-	0.0033
	Ca	0.29	0.28	0.30	0.30	0.28	0.35	-	*	-	0.0014
	Mg	0.12	0.13	0.14	0.14	0.13	0.13	-	-	-	0.0004

- = not significant * = 5% significance level ** = 1% significance level

TABLE 6. Fertilizer and conditioning effects on the nutrient content (% dry weight) of interior spruce foliage.

Conditioning		Standard			Shallow			Treatment significance			
Fertilizer rate (g 4-12-8/plant)		0	1.25	2.50	0	1.25	2.50	Cond	Fert	CxF	Error Ms
Campbell River	N	2.20	2.20	2.19	2.08	2.23	2.17	-	-	-	0.0207
	P	0.29	0.29	0.30	0.28	0.26	0.25	**	-	*	0.0004
	K	0.64	0.68	0.62	0.69	0.68	0.65	-	-	-	0.0035
	Ca	0.69	0.67	0.68	0.59	0.60	0.56	**	-	-	0.0029
	Mg	0.16	0.13	0.13	0.11	0.12	0.10	**	-	-	0.0005
Surrey	N	1.94	2.49	2.44	1.34	1.71	2.06	**	**	*	0.0292
	P	0.25	0.25	0.24	0.18	0.22	0.22	**	*	**	0.0002
	K	0.54	0.57	0.53	0.47	0.54	0.56	-	-	*	0.0024
	Ca	0.93	0.97	1.02	0.87	0.82	0.80	**	-	-	0.0193
	Mg	0.10	0.10	0.10	0.10	0.10	0.10	-	-	-	0.0002
Skimikin	N	1.98	2.64	2.82	1.65	2.17	1.99	**	**	-	0.1069
	P	0.28	0.31	0.30	0.24	0.25	0.25	**	-	-	0.0003
	K	0.85	0.76	0.71	0.79	0.77	0.73	-	**	-	0.0047
	Ca	1.04	1.15	1.19	1.20	1.17	1.13	-	-	-	0.0485
	Mg	0.16	0.18	0.18	0.13	0.15	0.17	**	**	*	0.0002
Red Rock	N	1.84	2.19	2.32	1.77	2.02	2.17	**	**	-	0.0177
	P	0.16	0.17	0.16	0.13	0.14	0.14	**	-	-	0.0002
	K	0.55	0.60	0.59	0.45	0.56	0.56	**	**	-	0.0013
	Ca	0.64	0.66	0.69	0.63	0.61	0.69	-	-	-	0.0059
	Mg	0.14	0.16	0.16	0.13	0.15	0.16	*	**	-	0.0001

- = not significant * = 5% significance level ** = 1% significance level

TABLE 7. Fertilizer and conditioning effects on the nutrient content (% dry weight) of interior spruce stem tissue.

Conditioning		Standard			Shallow			Treatment significance			
Fertilizer rate (g 4-12-8/plant)		0	1.25	2.50	0	1.25	2.50	Cond	Fert	CxF	Error Ms
Campbell River	N	1.72	1.58	1.54	1.57	1.71	1.61	-	-	-	0.0392
	P	0.29	0.26	0.26	0.25	0.25	0.24	-	-	-	0.0012
	K	0.56	0.53	0.56	0.62	0.59	0.59	**	-	-	0.0028
	Ca	0.37	0.32	0.34	0.33	0.30	0.33	*	-	-	0.0011
	Mg	0.11	0.10	0.11	0.10	0.09	0.10	*	-	-	0.0002
Surrey	N	1.18	1.59	1.65	0.89	1.12	1.36	**	**	-	0.0225
	P	0.22	0.21	0.21	0.15	0.18	0.18	**	-	**	0.0004
	K	0.53	0.47	0.47	0.46	0.48	0.47	-	-	*	0.0016
	Ca	0.35	0.34	0.35	0.31	0.33	0.32	**	-	-	0.0004
	Mg	0.10	0.10	0.10	0.10	0.10	0.10	-	-	-	0.0001
Skimikin	N	1.13	1.46	1.54	0.72	1.14	1.12	**	**	-	0.0463
	P	0.20	0.21	0.22	0.18	0.19	0.19	**	-	-	0.0004
	K	0.62	0.61	0.52	0.61	0.59	0.60	-	-	-	0.0053
	Ca	0.36	0.35	0.35	0.33	0.34	0.33	*	-	-	0.0003
	Mg	0.13	0.15	0.15	0.14	0.15	0.16	-	**	-	0.0001
Red Rock	N	1.23	1.59	1.87	1.20	1.61	1.67	-	**	-	0.0259
	P	0.15	0.17	0.17	0.14	0.15	0.15	**	**	-	0.0001
	K	0.53	0.55	0.57	0.50	0.56	0.58	-	**	-	0.0008
	Ca	0.28	0.27	0.27	0.28	0.25	0.27	-	*	*	0.0003
	Mg	0.13	0.13	0.13	0.12	0.12	0.13	-	-	*	0.0001

- = not significant * = 5% significance level ** = 1% significance level

TABLE 8. Fertilizer and conditioning effects on the nutrient content (% dry weight) of interior spruce root tissue.

Conditioning		Standard			Shallow			Treatment significance			
Fertilizer rate (g 4-12-8/plant)		0	1.25	2.50	0	1.25	2.50	Cond	Fert	CxF	Error Ms
Campbell River	N	1.62	1.44	1.62	1.50	1.76	1.82	**	**	**	0.0154
	P	0.25	0.25	0.27	0.26	0.25	0.23	-	-	**	0.0002
	K	0.46	0.46	0.47	0.49	0.50	0.47	*	-	-	0.0007
	Ca	0.28	0.28	0.27	0.23	0.23	0.22	**	-	-	0.0002
	Mg	0.11	0.10	0.10	0.11	0.11	0.10	-	*	-	0.0001
Surrey	N	1.27	1.92	1.92	0.99	1.30	1.63	**	**	**	0.0211
	P	0.24	0.26	0.25	0.20	0.23	0.23	**	-	-	0.0004
	K	0.46	0.40	0.39	0.38	0.34	0.43	-	-	**	0.0014
	Ca	0.35	0.30	0.29	0.31	0.26	0.29	*	**	-	0.0010
	Mg	0.12	0.12	0.12	0.13	0.15	0.13	**	*	-	0.0001
Skimikin	N	0.96	1.56	1.86	0.80	1.50	1.72	-	**	-	0.0299
	P	0.21	0.25	0.23	0.23	0.23	0.21	*	**	-	0.0003
	K	0.48	0.45	0.38	0.46	0.44	0.37	-	**	-	0.0013
	Ca	0.35	0.30	0.29	0.31	0.26	0.29	*	**	-	0.0069
	Mg	0.12	0.12	0.12	0.13	0.14	0.16	-	*	-	0.0003
Red Rock	N	1.42	2.05	2.41	1.47	2.02	2.03	-	**	-	0.0495
	P	0.15	0.16	0.15	0.13	0.15	0.14	*	-	-	0.0003
	K	0.42	0.40	0.35	0.40	0.36	0.34	*	**	-	0.0008
	Ca	0.40	0.40	0.41	0.40	0.35	0.42	-	-	-	0.0027
	Mg	0.13	0.12	0.10	0.12	0.10	0.40	-	**	-	0.0002

- = not significant * = 5% significance level ** = 1% significance level

TABLE 9. Nutrient content (% dry weight) of lodgepole pine (Red Rock) tissues as affected by conditioning and fertilizer treatments.

Conditioning		Standard			Shallow			Treatment significance			
Fertilizer rate (g 4-12-8/plant)		0	1.25	2.50	0	1.25	2.50	Cond	Fert	CxF	Error Ms
Needles	N	1.33	2.07	1.89	1.25	1.65	1.79	**	**	*	0.0350
	P	0.15	0.16	0.16	0.13	0.14	0.14	**	-	-	0.0002
	K	0.63	0.66	0.70	0.55	0.60	0.62	**	*	-	0.0044
	Ca	0.32	0.33	0.35	0.33	0.34	0.36	-	**	-	0.0006
	Mg	0.11	0.12	0.13	0.11	0.12	0.13	-	**	-	0.0001
Stems	N	0.63	1.13	1.09	0.76	1.01	1.12	-	**	*	0.0147
	P	0.12	0.13	0.12	0.11	0.12	0.12	**	*	-	0.0001
	K	0.59	0.63	0.58	0.48	0.50	0.57	**	-	-	0.0052
	Ca	0.20	0.20	0.20	0.21	0.23	0.20	-	-	-	0.0004
	Mg	0.13	0.13	0.13	0.13	0.13	0.13	-	-	-	0.0002
Roots	N	0.74	1.36	1.34	0.80	1.23	1.39	-	**	-	0.0153
	P	0.13	0.13	0.13	0.12	0.13	0.13	-	-	-	0.0001
	K	0.42	0.45	0.46	0.42	0.42	0.41	*	-	-	0.0008
	Ca	0.24	0.29	0.28	0.27	0.30	0.28	-	-	-	0.0036
	Mg	0.10	0.10	0.10	0.11	0.11	0.10	*	-	-	0.0001

- = not significant * = 5% significance level ** = 1% significance level

TABLE 10. Nutrient content (% dry weight) of interior Douglas-fir tissues as affected by conditioning and fertilizer treatments.

Conditioning		Standard			Shallow			Treatment significance			
Fertilizer rate (g 4-12-8/plant)		0	1.25	2.50	0	1.25	2.50	Cond	Fert	CxF	Error Ms
Needles	N	1.50	2.04	2.29	1.24	1.89	2.19	-	**	-	0.0695
	P	0.24	0.26	0.26	0.21	0.22	0.24	**	-	-	0.0008
	K	1.27	0.96	0.96	1.02	0.96	0.93	-	**	-	0.0197
	Ca	0.76	0.71	0.75	0.72	0.72	0.70	-	-	-	0.0023
	Mg	0.15	0.15	0.15	0.16	0.16	0.17	*	-	-	0.0001
Stems	N	0.73	1.04	1.31	0.59	0.98	1.13	*	**	-	0.0320
	P	0.15	0.15	0.17	0.12	0.14	0.14	**	**	-	0.0003
	K	0.53	0.47	0.49	0.39	0.44	0.40	**	-	**	0.0016
	Ca	0.32	0.30	0.31	0.31	0.32	0.29	-	-	-	0.0013
	Mg	0.10	0.10	0.10	0.09	0.10	0.09	-	-	-	0.0001
Roots	N	0.77	1.03	1.29	0.86	1.00	1.34	-	**	-	0.0253
	P	0.16	0.17	0.17	0.14	0.15	0.15	*	-	-	0.0004
	K	0.44	0.43	0.41	0.41	0.43	0.40	-	-	-	0.0010
	Ca	0.47	0.51	0.51	0.49	0.60	0.69	**	**	**	0.0036
	Mg	0.11	0.10	0.09	0.10	0.10	0.10	-	-	-	0.0001

- = not significant * = 5% significance level ** = 1% significance level

interior Douglas-fir. Both stem increases occurred at Campbell River: N in Sitka spruce and K in interior spruce. In the foliage, only Mg of interior Douglas-fir was increased by shallow conditioning. The late application of fertilizer increased the percent nutrient content, but here, too, exceptions occurred. Interactions between conditioning and fertilizer, caused by the failure of the standard-conditioned stock to respond to fertilizer application, are not uncommon. The shallow conditioned stock can respond positively - the N content of the tissues of Douglas-fir, Sitka spruce, interior spruce (Surrey), and lodgepole pine; or negatively - P content of interior spruce foliage and roots at Campbell River, K content of coastal Douglas-fir roots, and K content of Sitka spruce stems. Reductions in nutrient content in both conditioning treatments was confined to K content in the foliage of interior Douglas-fir, the foliage and roots of interior spruce (Skimikin), and the roots of interior spruce (Red Rock).

Discussion

Shallow conditioning improved the RGC of fertilized, unstored stock of all species except for the lodgepole pine and interior spruce grown at Red Rock.

Coastal Douglas-fir was lifted at the beginning of November, a time considered to be too early to allow adequate cold hardening in seedlings so that they can withstand storage at 2°C (Duryea and Lavender 1982; van den Driessche 1983). The RGC of the standard-conditioned stock did not improve in storage, supporting this hypothesis, nor did shallow conditioning improve the RGC of stored coastal Douglas-fir. Where coastal Douglas-fir is not stored (i.e., autumn planted), a significant improvement in its RGC can be obtained with shallow conditioning combined with late fertilizer application.

Although October/November lifting is also considered to be early for the other conifers used, the standard-conditioned stock improved in RGC following storage -- an indication that some cold hardiness had developed. Storage reduced the RGC of some species that were shallow conditioned, but only in the case of lodgepole pine was the RGC of stored shallow-conditioned stock less

than that of stored standard-conditioned stock. In most cases, RGC of stored shallow-conditioned stock was better than that of stored standard-conditioned stock.

Shallow conditioning causes a drop in the N and P content of Pinus radiata foliage (Van Dorsser and Rook 1972; Benson and Shepherd 1977; Donald 1983) and caused reductions with the species used in these trials. Similar results have been recorded for the N and P content of Douglas-fir following standard conditioning in late summer (van den Driessche 1983). This drop in nutrient level causes a yellowing of the foliage, which indicates that the conditioning is having the desired effect. Late fertilizer application changes the trend, improving the nutrient content and improving the RGC of seedlings (Donald 1983).

Stupendick (1977) has shown that Pinus radiata growing in a nutrient-deficient situation is unable to respond to shallow conditioning, the RGC being much more poor than that of seedlings given an adequate nutrient supply. In the trials described here, the late application of 1.25 g 4-12-8 per seedling improved the RGC of both Red Rock species (lodgepole pine and interior spruce) regardless of which conditioning treatment was used. The response in most cases was quadratic, with the 2.5-g level not differing significantly from the 1.25-g level.

The quantity of nutrient applied per seedling using 1.25 g 4-12-8 complete fertilizer was 50 mg N, 150 mg P, and 100 mg K; or, with a stocking of 200 seedling m^{-2}, 100 kg N, 300 kg P, and 200 kg K/ha. These rates are high, but N levels are similar to those used by other researchers in North America: on Douglas-fir van den Driessche (1982) used up to 175 kg N/ha in one experiment, and up to 240 kg N/ha in another (van den Driessche 1983); and on Picea glauca Mullin and Bowdery (1977) used up to 122 kg N/ha, while Armson (1963) used up to 136 kg N/ha. Phosphorus and K application rates were significantly higher than normally used in North America, probably because the ratios were based on South African data (Donald 1972) where soil P and K levels - particularly P - are much lower than in British Columbia. Most of the above researchers used lower quantities of P and K than of N, not higher as used in the trials reported in this study; however, van den Driessche (1983) used 524 kg P/ha and 240 kg K/ha in his trial.

The technique of prescribing fertilizer per seedling rather than per area is based on the hypothesis that nursery plants must be regarded singly and that their individual espacement is of major importance. Seedling espacement was not part of this trial, and bed densities, particularly at Red Rock, were much higher than are customary in South African nurseries where bed density seldom exceeds 175 m^{-2}. The number of usable seedlings were taken from the latest available stock-taking surveys for the beds in which the trials were sited. Red Rock had over 400 seedlings m^{-2}, Skimikin had about 300, while both Campbell River and Surrey had less than 200 seedlings m^{-2}.

The salt concentrations of the 2.5 g 4-12-8 per seedling treatments at Red Rock, with over 400 seedlings m^{-2}, killed over 90% of the plants and it was only with difficulty that apparently healthy seedlings could be found for RGC measurement, laboratory enumerations, and field planting. The 2.5-g level also caused some mortality at Skimikin with 300 seedlings m^{-2}. All treatments were divided in half and applied at weekly intervals at Surrey and Campbell River. No mortality was recorded at either nursery.

There is good evidence that seedling density influences plant growth, the highest densities giving large numbers of culls and poorer field performances (Van Dorsser 1969; Benson and Shepherd 1977; Mullin and Bowdery 1977; Bowles 1981; van den Driessche 1982). British Columbia is already using lower densities, and therefore the 50 mg N per seedling appears to be an acceptable amount. Phosphorus and K levels are likely to need considerable modification, however. Recent work in South Africa indicates that 35 mg P per seedling is optimum for Pinus radiata, and that K should not be added because it inhibits RGC (Donald 1983).

By and large, the significant nutrient response to treatment in the tissues of these British Columbia species was as expected. Shallow conditioning reduced the percent nutrient content below that of standard conditioning and late fertilizer application corrected it. Shallow conditioning following late fertilizer application that increased the nutrient content over that achieved by the standard treatment was probably due to greater root activity in the newly developed root system. Not only is the

percent N and P of the root system improved, e.g. in Sitka spruce, but the total N and P content in the tissue is also greater (Table 11) even though the total dry weight of Sitka spruce was decreased by shallow conditioning.

Percent K content of tissues was reduced in several instances following the application of fertilizers containing this element, and increased in others. The reasons for this inconsistent response are unknown. In the case of Sitka spruce stems, the total K content of shallow-conditioned stock stems was not reduced by fertilizer application (Table 12), suggesting a dilution effect. However, with Douglas-fir roots, both the coastal and interior varieties showed a drop in percentage and total K content following fertilizer application. It is possible that the quantities of K applied were too high and the negative effect was due to root damage inhibiting uptake.

Several authors have reported a drop in shoot length and shoot dry weight following standard conditioning (Shoulders 1963; Duryea and Lavender 1982; Tanaka et al. 1976; van den Driessche 1983), and it is an accepted phenomenon with shallow conditioning (Rook 1971; Van Dorsser and Rook 1972; Benson and Shepherd 1977). In the present experiment, a lack of reduction in height growth and root collar diameter, and a fairly limited reduction in dry weight, indicates that shoot growth had already stopped before conditioning treatments commenced. All four nurseries had restricted irrigation prior to beginning these trials at the end of July. Although irrigation was recommenced, it appears likely that the water stress had induced early shoot dormancy. Blake et al. (1979) have shown the height growth of Douglas-fir did not recommence following induced water stress in mid-July, even though the plants were subsequently well watered. Tanaka et al. (1976), working with Douglas-fir, also failed to register a height response to standard conditioning over the July to October period. Their treatments did, however, stimulate root dry weight.

The failure of shallow conditioning to improve the RGC at Red Rock is considered to be due to the inability of the Marsh reciprocating wrencher to stress the plants sufficiently. The RGC of the Red Rock plants was already much higher than that of the same species grown at other nurseries, yet both interior spruce and lodgepole pine responded well to the late application of

TABLE 11. Total N and P content of Sitka spruce roots (mg)

Conditioning	Standard			Shallow		
Fertilizer rate (g 4-12-8/plant)	0	1.25	2.50	0	1.25	2.50
N	13.6	14.6	17.8	13.2	24.4	28.5
P	2.2	2.7	2.9	2.1	3.3	3.6

TABLE 12. Total K content of Sitka spruce stems (mg)

Conditioning	Standard			Shallow		
Fertilizer rate (g 4-12-8/plant)	0	1.25	2.50	0	1.25	2.50
K	11.2	11.1	11.2	7.5	9.7	9.3

1.25 g fertilizer. In other words, RGC can be improved by treatment, in this case 1.25 g 4-12-8 per seedling, but perhaps also by properly applied shallow conditioning.

Conclusion

Shallow conditioning combined with late fertilizer application has considerable potential to improve the RGC of the conifers grown in British Columbia bareroot nurseries. In the case of coastal Douglas-fir, the treatment does not improve, as RGC; however, for Sitka spruce, interior Douglas-fir, and the interior spruces, RGC of stored fertilized shallow-conditioned stock is as good as, or better than, that of the stored standard-conditioned plants. More work is required to determine optimum nutrition for the different species, particularly with regard to P and K levels.

FIELD PERFORMANCE

Methods and Materials

Table 13 summarizes the planting site information. All six nursery variables were carried forward into field plantings, where an additional split-plot variable was added. The split-plot was planting time -- autumn 1979 and spring 1980, for the two coastal species, Douglas-fir and Sitka spruce; and depth of planting -- nursery level and 5 cm deeper than nursery level, in the remaining species. The field plantings were therefore 2 x 3 factorials plus split-plot, laid out in randomized blocks, each with six replications. Plots consisted of two straight lines of 25 trees running at right angles to a base line. The sub-plot whose trees were to be planted 5 cm deeper than normal was decided by tossing a coin. Because of vigorous regrowth of natural vegetation, often including natural regeneration of the test species, planted trees are frequently difficult to locate after a year. To simplify their location and identification, a collar of 12-gauge galvanized wire, 9.5 cm in diameter, was placed around each planted tree. Their location could then be determined fairly easily with a metal detector.

Survival and height of interior Douglas-fir, the interior spruces, and lodgepole pine were measured in October 1981, and Sitka spruce was measured in March 1982. Lodgepole pine was again measured in 1983. It has not been possible to evaluate the coastal Douglas-fir trial. All data was subjected to analysis of variance.

Results

Survival after field planting

Table 14 summarizes the significant survival responses. Survival of interior spruce raised at Surrey was slightly but significantly improved by shallow conditioning and by deep planting. Shallow conditioning had no effect on the survival of the other trials. Deep planting improved the 1st year survival of shallow-conditioned lodgepole pine raised at Red Rock.

TABLE 13. Details of planting trials derived from conditioning/fertilizer trials.

Nursery	Species	Date lifted from nursery	Date Planted	Field Site	Lat (N) & Long (E)	Elev (m)
Red Rock	*Pinus contorta*	Oct. 1979	May 1980	Fort St. James	54° 30' 124° 10'	760
Red Rock	*Picea glauca*	Oct. 1979	May 1980	Fort St. James	54° 30' 124° 10'	760
Skimikin	*Picea engelmannii*	Oct. 1979	June 1980	Sicamous	50° 50' 118° 44'	1600
Skimikin	*Pseudotsuga menziesii* var. *glauca*	Oct. 1979	Apr. 1980	Trinity Valley	49° 23' 118° 44'	800
Campbell River	*Pseudotsuga menziesii*	Nov. 1979	Nov. 1979 Apr. 1980	Tree Farm Lic. 36	50° 32' 125° 25'	305
Campbell River	*Picea sitchensis*	Nov. 1979	Nov. 1979 Jan. 1980	Carnation Creek	48° 56' 125° 00'	50
Campbell River	*Picea glauca*	Nov. 1979	May 1980	Fort St. James	54° 30' 124° 10'	760
Surrey	*Picea glauca*	Nov. 1979	June 1980	Dawson Creek	54° 50' 120° 45'	762

TABLE 14. Survival of 2+0 nursery stock as affected by conditioning, depth of planting, and late fertilizer application

Species	Variable	Combining fertilizer levels	SE	LSD ($p \leq .05$)
Interior spruce (Surrey)	Standard conditioning	98.6	0.44	0.90
	Shallow conditioning	99.8		
Interior spruce (Surrey)	Normal depth	98.7	0.38	0.77
	Deep planted	99.7		
Lodgepole pine (shallow-conditioned only)	Normal depth	95.4	1.50	3.06
	Deep planted	98.8		

Species	Type of Conditioning	Fertilizer rates (g 4-12-8/seedling) 0	1.25	2.50	SE	LSD ($p \leq 0.05$)
Sitka spruce (autumn planting only)	Both	98.0	90.2	94.2	2.90	5.92
Lodgepole pine (Red Rock)	Both	99.7	98.2	95.1	1.66	3.42
Interior spruce (Red Rock)	Both	98.5	94.7	89.7	1.94	4.00
Interior Douglas-fir (Skimikin)	Shallow	100.0	98.0	95.7	1.15	2.36
Interior spruce (Skimikin)	Shallow	99.2	98.8	74.9	2.73	5.62

The low rates, but not the high rate of late fertilizer application, reduced the survival of autumn-planted Sitka spruce raised at Campbell River. The high rate reduced survival of lodgepole pine and interior spruce raised at Red Rock. The rate also reduced the 1st year survival of shallow-conditioned species raised at Skimikin. Survival of interior spruce raised at Campbell River and at Surrey was not affected by late fertilizer application, nor was the survival of standard-conditioned plants raised at Skimikin. Time of planting, autumn or spring, had no effect on the survival of Sitka spruce raised at Campbell River. After 3 years, no treatment differences were significant for lodgepole pine, the mean survival for the trial being 90.8%.

Height increment

Shallow conditioning significantly reduced the first field season increment of lodgepole pine and the interior spruces (Table 15). It had no effect on the 1st year increment of interior Douglas-fir or on the increment of Sitka spruce after 2 years. After 3 years, the current year (1982) height increment of lodgepole pine was not affected by conditioning, although the shallow-conditioned plants were still significantly smaller than those that received the standard treatment (Table 16).

Late fertilizer application in the nursery increased the 1st year height increment of lodgepole pine and the interior spruces grown at Skimikin and Red Rock (Table 15). The interior spruces grown at Campbell River responded significantly to the 2.50-g level, only when shallow conditioned. Interior Douglas-fir planted at Trinity Valley was severely browsed by grouse. The mean increment of the five tallest plants per plot were analysed because it seemed likely that these had not been browsed. Late fertilizer application in the nursery significantly improved the height of these plants in the 1st year (Table 15).

After the second growing season (first enumeration), height increment of Sitka spruce that had received the standard conditioning was significantly reduced by the low rate of late fertilizer application, but

TABLE 15. Conditioning and late fertilizer effects on first field season height increment (cm) of 2+0 bareroot conifer stock

Species	Conditioning regime		SE	LSD	Fertilizer rate (g 4-12-8/seedling)			SE	LSD
	Standard	Shallow		($p \leq 0.05$)	0	1.25	2.50		($p \leq .05$)
Lodgepole pine	9.7	8.2	0.4	0.8	8.3	9.5	9.1	0.5	0.9
Interior spruce									
Surrey	6.7	6.0	0.2	0.4	-	-	-		
Skimikin	7.7	6.2	0.3	0.6	6.4	7.6	6.8	0.4	0.8
Red Rock	5.2	4.5	0.3	0.6	4.4	5.3	4.8	0.3	0.7
Campbell River*	8.3	7.5	0.2	0.4	6.9	7.4	8.1	0.6	0.9
Douglas-fir	-	-			5.9	8.5	8.3	0.4	1.0
Sitka spruce**	-	-			22.3	18.6	21.7	1.0	2.9

* Fertilizer response for shallow-conditioned plants only.
**Fertilizer responses for second field season increment on standard-conditioned plants only.

TABLE 16. Height increment (cm) of lodgepole pine for the third field growing season as affected by conditioning and fertilizer. (Total height at 3 years given in parenthesis.)

Conditioning treatment	Fertilizer rate (g 4-12-8/seedling) 0	1.25	2.50	Means
Standard	9.8 (35.6)	9.4 (37.7)	10.3 (37.3)	9.8 (36.8)
Shallow	8.9 (33.5)	10.2 (36.4)	9.9 (36.5)	9.7 (34.9)
Means	9.3 (34.6)	9.8 (36.9)	10.1 (36.0)	

Variable	Height increment SE	LSD ($p \leq .05$)	Total height SE	LSD ($p \leq .05$)
Conditioning	NS*	-	0.7	1.3
Fertilizer	NS	-	0.8	1.6
C x F	0.6	1.2	NS	-

*NS = F ratio in analyses of variance not significant.

not by the high rate. Shallow-conditioned stock was not affected. Late fertilizer application continued to improve (although not significantly) height increment of shallow-conditioned lodgepole pine after 3 years. Both conditioning and fertilizer treatment gave significant responses when total height was analysed, however (Table 16).

Deep planting significantly improved first field season height increment of all interior spruce trees, either directly, as with plants raised at Skimikin and Red Rock, or indirectly through interaction with conditioning or fertilizer application, as with plants raised at Surrey and Campbell River (Table 17). Fertilizer increased the height increment of deep-planted shallow-conditioned plants raised at Surrey in a linear manner, while it increased deep-planted standard-conditioned plants and all normally planted plants quadratically. Only deep-planted plants from Campbell River responded to fertilizer, and only standard-conditioned plants benefited from deep planting (Table 17a-c).

Discussion

Shallow conditioning had minimal effect on the survival of species used in these trials. Only in one trial was survival improved and although this difference was significant (at the 5% level), it was not of practical importance because of the excellent survival of the standard-conditioned plants. Shallow conditioning reduced the initial height increment of lodgepole pine and the interior spruces. While it is possible that the treatment affected bud development and subsequent shoot elongation in the year after planting, it seems more likely that the reduction was due to a shortage of stored photosynthate. Shallow conditioning greatly stimulates root development that uses current photosynthate and reduces stored photosynthate in the stem (Rook 1971; Stupendick 1977). Height growth in north temperature conifers is dependent upon stored photosynthate (Kozlowski and Winget 1964; Kruger and Trappe 1967) which, because of the drain to the roots during shallow conditioning, would be appreciably less in the shallow-conditioned plants. If this hypothesis is correct, then subsequent growth of

TABLE 17a. The effect of planting depth on first field season height increment (cm) of 2+0 bareroot interior spruce seedlings

Nursery	Normal depth	Deep planted	SE	LSD ($p \leq .05$)
Red Rock	4.7	5.0	0.1	0.2
Skimikin	6.7	7.6	0.4	0.8

TABLE 17b. The effect of planting depth, conditioning, and fertilizer application on first field season height increment (cm) of 2+0 bareroot interior spruce seedlings

Nursery	Planting depth	Type of conditioning	Fertilizer rate (g 4-12-8/seedling) 0	1.25	2.50	SE	LSD ($p \leq .05$)
Surrey	Normal	Standard	6.3	6.7	6.6	0.1	0.3
		Shallow	5.6	6.2	5.8		
	Deep	Standard	6.8	7.0	6.9		
		Shallow	5.7	6.3	6.6		
Campbell River	Normal		7.8	7.7	7.7	0.2	0.5
	Deep		7.6	8.3	8.2		

TABLE 17c. The effect of planting depth and conditioning on first field season height increment (cm) of 2+0 bareroot interior spruce seedlings

Nursery	Planting depth	Standard conditioning	Shallow conditioning	SE	LSD ($p \leq .05$)
Campbell River	Normal	8.0	7.5	0.2	0.3
	Deep	8.6	7.5		

shallow-conditioned seedlings should improve. Second-year increment of Sitka spruce and 3rd year increment of lodgepole pine -- the only trials measured beyond the 1st year -- do not show significant differences in increment between the conditioning treatments. Total height of shallow-conditioned lodgepole pine seedlings was still significantly less than that of standard-conditioned plants even after 3 years, however.

The late application of the highest fertilizer level to nursery seedlings some 50 days prior to lifting reduced the 1st year survival of lodgepole pine and interior spruce raised at Red Rock, and interior Douglas-fir and interior spruce raised at Skimikin. Seedling densities at Red Rock and Skimikin were extremely high so that the quantities of fertilizer applied in one application at these nurseries caused severe root scorch. It is perhaps surprising that the survival levels of these seedlings were not much worse. Survival of plants receiving the 1.25-g level did not differ from the unfertilized control in any of the trials except for autumn-planted Sitka spruce. Seedling densities in the Sitka spruce beds were much lower and the fertilizer was applied in two equal does so that root damage was unlikely to have caused the survival reduction, particularly as the highest fertilization level did not differ from the control. A reduction in resistance to winter cold caused by the 1.25-g fertilizer application cannot be ruled out, but also seems unlikely because plants receiving the highest level did not respond in the same way, yet had an increased uptake of nutrients (Table 11). Whatever caused the reduced survival of these particular plants also caused a reduction in their height increment, and thus it seems likely that these results were not due to treatment, but rather, to external uncontrolled factors. Height increment of all the interior species was improved by the late application of fertilizer in the nursery. In most cases, the response was quadratic with the 2.50-g level not giving an additional response above that of the 1.25-g level.

Late fertilizer application in the nursery has been tried by several authors with somewhat varied results. Anderson and Gessel (1966) reported height responses to autumn nitrogen application (60 kg N/ha) for up to 5 years after planting Douglas-fir. Not all sites gave significant responses, but the

trend in all cases was positive. Survival was also significantly improved. Seedling density was not given so the amount of N per seedling cannot be compared. Anderson and Gessel (1966) quote Stoeckler and Arnemann (1960) who suggest that improved survival is the major factor in late fertilization and that growth responses are unlikely to persist beyond a few years. Van den Driessche (1983) reported a drop in cold hardiness (as measured by electrical impedance) with increasing levels of fertilizer applied to Douglas-fir, particularly if the seedlings were tested before adequate naturally induced cold resistance had developed. Benzian et al. (1974) reported measurable height responses for 3 years with Sitka spruce following late applications in the nursery, but minimal responses from Norway spruce, western hemlock, and lodgepole pine; negative responses were obtained from Abies grandis. None of the species she tested were adversely affected for survival.

In the trials in this study, survival was not adversely affected by the lowest fertilizer rate, and height increment, at least for the interior species, was significantly improved. It appears that late fertilizer application in the nursery holds sufficient promise to warrant further work, particularly on the type and rate of elements to be applied.

Pines planted at least 5 cm deeper than they stood in the nursery, survived and grew significantly better than those planted at the nursery level (Donald 1970; Balneaves and Cullen 1981). This was particularly the case where the planting sites have long periods of dry weather. British Columbia frequently experiences drought periods in spring and early summer so that deep planting could be expected to be beneficial. This proved to be so in the present experiments, even though the moisture supply during the initial year was unusually favourable. Deep planting is more expensive, but the better survival and growth achieved is likely to warrant the cost. On gleyed heavy clays, deep planting may adversely affect survival, but on adequately drained soils, it warrants serious consideration.

No correlation between RGC and survival could be found in any of these trials. Burdett (1979), Sutton (1980), Burdett et al. (1983), and van den Driessche (1983) have demonstrated positive correlations between RGC and field survival, and Ritchie and Dunlap (1980) list 18 studies on conifers

where correlation between RGC and field survival has been good to strong. Where survival is high, the overall quality of the planting stock is good, and moisture stress in the early weeks after planting is low (as in these trials), the relationship between RGC and survival has proved much more difficult to demonstrate (Donald 1983).

Conclusion

Four main conclusions were drawn from the field performance of these conditioning/fertilizer trials:

1. Although shallow conditioning can improve the RGC of the conifers raised in British Columbia bareroot nurseries, its value is limited due to its apparent inability to induce early cold hardiness. Survival of the standard-conditioned stock is quite acceptable.
2. Late fertilizer application in the nursery can improve the early growth of the planted tree, without adversely affecting survival. Determining type and rate of fertilizer requires further work to provide satisfactory prescriptions for each species.
3. Deep planting of interior species is recommended as an inexpensive and effective way of improving their field establishment.
4. Autumn planting of Sitka spruce appears to be an acceptable technique for plantation establishment on the west coast of British Columbia.

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